Resonance studies at STAR

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We report on the observed signals of $K^{*0}(892) \rightarrow \pi K$ and $\phi(1020) \rightarrow K^+ K^-$ using the mixed-event method with powerful statistics from the large acceptance and high efficiency of the STAR TPC. Preliminary results from the first observation of such states from the year-one STAR data in $\sqrt{s_{NN}} = 130 \text{GeV}$ Au+Au collisions are presented. The K^{*0}/h^- ratio, assuming an inverse slope of 300MeV for the K^{*0}, is compatible with that from pp collisions at the ISR. For 14% central Au+Au collisions, we find $K^{*0}/h^- = 0.060 \pm 0.007(stat)$ and $\overline{K^{*0}}/h^- = 0.058 \pm 0.007(stat)$. We also show that with this method we measure $\overline{\Lambda}/\Lambda = 0.77 \pm 0.07(stat)$, consistent with the value from topological reconstruction.

1. Introduction

Resonance (vector meson, etc.) production and the modification of their properties in-medium are important signals of a possible phase transition of nuclear matter in relativistic heavy ion collisions. Despite the dominance of hadronic decay modes for vector mesons, only their leptonic decays have been extensively studied [2]. This is due in large part to the final state interactions of the hadronic decay products, large backgrounds from the other produced hadrons (π's,K's), and the broad mass width of the hadronic decay channels. This is especially true for mesons like the $\rho(770)$ and $K^{*0}(892)$ whose daughters include π's, and whose decay widths are 130MeV and 50MeV respectively. But the short lifetimes which make these measurements difficult may also make them interesting: their lifetimes are comparable to the lifetime of the dense matter in which they are produced. Their measured properties may thus be sensitive to the lifetime of the dense matter. For example, model calculations show that the K^{*0}/K ratio is sensitive to the mass modification [3] of particles in-medium and the dynamic evolution of the source. From detailed comparisons between the yields and p_T distributions of resonances and other particles we may be able to distinguish different freeze-out conditions [4,5].

Simulations have shown that we should be able to reconstruct these resonances with good statistics at RHIC energies through the mixed-event method because the significance of the signal rises with the square root of number of events [6]. However, complications from detector effects and flow effects become significant when the signal is less than 1% of the combinatorics. This method can also be used to reconstruct weak decays (Λ, $\overline{\Lambda}$, and K_S^0) complementary to those measurements through topological reconstruction.

2. Experimental setup and data analysis

The main detector for STAR is the Time Projection Chamber(TPC) [1] which measures the multiplicity and momenta of charged tracks. Additionally, coincidences between Zero Degree Calorimeters (ZDC) define a minimum bias trigger and a scintillating Central Trigger Barrel (CTB) is used to select the top 14% central events [1]. The STAR TPC's
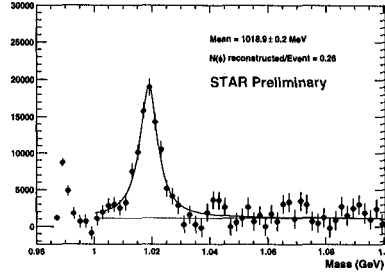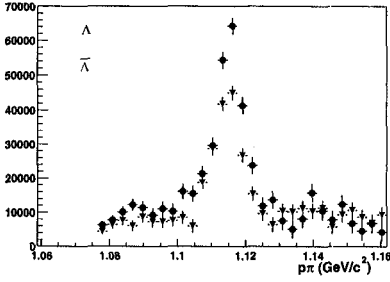
Figure 1. Λ and $\overline{\Lambda}$ mass plot after mixed- Figure 2. ϕ mass plot after mixed-event event background subtraction from 160K background subtraction from 400K cen- minbias events, $\overline{\Lambda}/\Lambda = 0.77 \pm 0.07(stat)$. tral event.

large acceptance ($\approx$95%) and high efficiency ($\approx$85%) at mid-rapidity ($|y| < 0.5$) help us to overcome the large combinatoric backgrounds in this analysis.

Data were taken in the summer of 2000 for Au+Au collisions at $\sqrt{s_{NN}} = 130$GeV [7]. There are 307K central and 160K minimum bias Au+Au nuclear interactions used in this analysis which survive the cuts described below. The collision event vertex is required to be within $|Z|$<95cm along the beam direction through the center of the TPC for uniform acceptance in the pseudorapidity range we study [8]. Particles are selected based on their momenta (measured with the TPC from the track curvature in a 0.25T solenoidal magnetic field), track quality, and particle identification (from energy loss in the TPC). The cuts used depend on the daughter particle species. Since the daughters of $K^{\star 0}$ and ϕ decays originate from very near the interaction point, we select tracks with $DCA < 3$cm, where DCA is the distance of closest approach to the primary vertex. For the daughters of Λ and $\overline{\Lambda}$ decays (with $c\tau$=7.8cm) we select tracks with $DCA < 7$cm. The purity of the particle identification selection is good only at low momentum. In addition, we impose restrictions on the pseudorapidities of the daughters ($|\eta| < 0.8$) and the opening angles between them ($\Delta\theta > 0.2$ for $K^{\star 0}$ and $\Delta\theta > 0.05$ for ϕ and Λ).

Figs.1 and 2 show the mixed-event subtracted mass plots for Λ, $\overline{\Lambda}$ and ϕ. For the Λ and $\overline{\Lambda}$, we limit the parent particle to $p_T < 2$GeV/c and $|y| < 0.5$ in addition to the cuts on the daughters. From these distributions, we fit the Λ and $\overline{\Lambda}$ mass peaks, and determine the p_T- and rapidity-integrated ratio of $\overline{\Lambda}/\Lambda = 0.77 \pm 0.07(stat)$ for minimum-bias events. The reconstruction efficiencies of Λ and $\overline{\Lambda}$ cancel out in this ratio due to the cylindrical symmetry of the TPC and its magnetic field. This ratio is consistent with the result of $\overline{\Lambda}/\Lambda = 0.73 \pm 0.03(stat)$ determined from the topological reconstruction method in STAR [8]. This value indicates that at midrapidity there is a non-zero net strange baryon number. We also observe $\sim$0.26 reconstructed $\phi \rightarrow K^+K^-$ (B.R. 49.1%) decays per central event.

$K^{\star 0} \rightarrow K^+\pi^-$ and its antiparticle $\overline{K^{\star 0}} \rightarrow K^-\pi^+$ (B.R. 67%) can be reconstructed from the charged kaons and pions. The invariant mass of every $K\pi$ pair from the same event and a pool of mixed events is calculated and entered in the same-event spectra and the mixed-event spectra seperately. Usually three or more events within centrality bins and with similar collision vertex locations ($|\Delta Z| < 10$cm) are "mixed" with each other. From the 307K 14% central events, there are more than 14×10^9 pairs of selected kaons and pions. Substantial computation is required to calculate both same-event spectra and mixed-event spectra. The invariant mass distribution of $K^+\pi^-$ after background subtraction is

shown in Fig.3 for these central events. The signal-to-background ratio before background subtraction is about 1/1000 for central events, 1/50 for peripheral Au+Au interactions and 1/4 for pp at ISR [9]. However, the important measure of the significance of the signal is not S/N but the ratio of signal to the fluctuation in the background: $S/\sqrt{N}$. We observe a 10 standard deviation σ K^{*0} signal above the background fluctuation, and the raw count of reconstructed K^{*0} decays is 2.7 per central event. Similarly, a 9σ $\overline{K^{*0}}$ signal is observed above the $K^-\pi^+$ combinatoric background with a raw count of 2.6 per central event. The masses and widths are measured to be $m_{K^{*0}} = 0.893 \pm 0.003\text{GeV}/c^2$, $\Gamma_{K^{*0}} = 0.058 \pm 0.015\text{GeV}/c^2$, $m_{\overline{K^{*0}}} = 0.896 \pm 0.004\text{GeV}/c^2$, and $\Gamma_{\overline{K^{*0}}} = 0.063 \pm 0.011\text{GeV}/c^2$. These are consistent with the values of $m_{K^{*0}} = 0.896\text{GeV}/c^2$ and $\Gamma_{K^{*0}} = 0.0505\text{GeV}/c^2$ in the Particle Data Book [10]. Linear and exponential shapes are used to fit the residual background under the signal as shown in Fig.3. The difference is about 20%, which is used to estimate the systematic error of the measurements. In order to get the yields, we have to calculate the detector acceptance and efficiency. This is done by embedding GEANT simulated kaons and pions into the real events, which then go through the full reconstruction chain [8]. The overall acceptance and efficiency factor ϵ depends on centrality, p_T, and rapidity of the parent and daughter particles. ϵ varies from under 20% for $p_T \simeq 0$ GeV/c to above 50% for $p_T \simeq 2.0\text{GeV}/c$. In current studies, only one integrated p_T and rapidity bin is used for each centrality from the data analysis. An inverse slope of $T = 300\text{MeV}$ and a flat rapidity distribution are assumed for K^{*0} to calculate the correction factor ε. $\varepsilon = 31\%$ for central events and increases for lower multiplicity events. However, because the efficiency increases with p_T, assuming $T = 600\text{MeV}$ results in $\varepsilon > 40\%$.
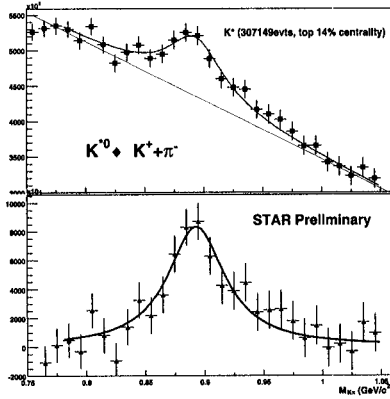
Figure 3. K^{*0} mass plot.
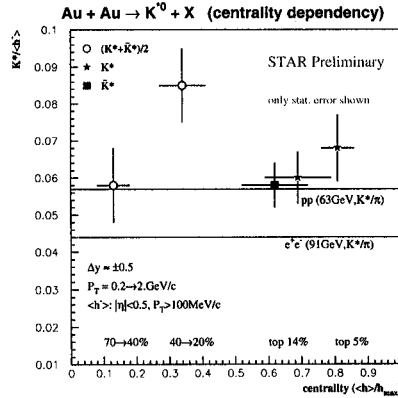
Figure 4. $K^{*0}/h-$ for four centrality bins.

3. Results and Discussion

We take the K^{*0}/h^- yield ratio and compare the results for different centralities, and with those from pp at ISR [9] and e^+e^- at LEP [11]. h^- is the corrected total primary negatively charged hadrons with $|\eta| < 0.5$ and $0.1 < p_T < 2.0\text{GeV}/c$ [8]. The preliminary results as shown in Fig.4 are $(K^{*0} + \overline{K^{*0}})/2h^- = 0.058 \pm 0.01$ for centrality bin of 70% to 40%, $(K^{*0} + \overline{K^{*0}})/2h^- = 0.085 \pm 0.01$ (40% → 20%), $\overline{K^{*0}}/h^- = 0.058 \pm 0.006$, $K^{*0}/h^- = 0.06 \pm 0.007$ (top 14%), and $K^{*0}/h^- = 0.068 \pm 0.009$ (top 5%) for four centrality bins. The shown errors are statistical only and the systematic errors are estimated to be about 25%.

These results are to be compared with $K^{\star0}/\pi = 0.044 \pm 0.003$ from e^+e^- at $\sqrt{s} = 91\text{GeV}$ and $K^{\star0}/\pi = 0.057 \pm 0.009 \pm 0.009$ from pp at $\sqrt{s} = 63\text{GeV}$. We observe that the ratio $K^{\star0}/h^-$ does not change much from low multiplicity to high multiplicity and is compatible with $K^{\star0}/\pi$ in elementary particle collisions. It should be noted that about 80% of h^- is π^-, and that h^- yield per participant pair in central Au+Au collisions increases by 30% from $p\bar{p}$ collisions at the same energies [8]. This implies an increase of $\sim$50% in the $K^{\star0}$ per participant pair. A better comparison can be made for $K^{\star0}/K$ since they have similar quark content and differ mainly by spin. By simple spin counting, the vector meson-to-meson (pseudoscalar+vector) ratio is $V/(P + V) = 0.75$. However, due to the mass difference between these two states, $V/(P + V)$ is much smaller from elementary collisions. Preliminary comparison indicates a ratio $K^{\star0}/K$ of 0.42 ± 0.14 in central Au+Au at RHIC, which is between the results of $K^{\star0}/K^{\pm} = 0.64(0.55) \pm 0.09 \pm 0.03$ at ISR and $K^{\star0}/K = 0.32 \pm 0.02$ at LEP. The preliminary kaon results are from [8].

However, since the lifetime of $K^{\star0}$ is short ($c\tau = 4\text{fm}$) and is comparable to the time scale of the evolution of the system, we need to take into account the survival probability of $K^{\star0}$ when comparing the results from Au+Au with those from pp. For example, during the time Δt between chemical freeze-out and kinetic freeze-out, the daughter K's and π's from $K^{\star0}$ decay may rescatter and the $K^{\star0}$ may not be reconstructed. A simple model simulation which assumes that a $K^{\star0}$ decaying before kinetic freeze-out cannot be reconstructed experimentally shows that Δt can only be on the order of a few fm/c with the current measured $K^{\star0}/K$ ratio. The consistency of the measured masses and widths of $K^{\star0}$ to the Particle Data Book values seems to indicate that the daughter K's and π's undergo no further small angle elastic scattering after they emerge from the dense matter. In reality, the survival probability depends on Δt, the source size, and the p_T of $K^{\star0}$. This may give us a unique tool to measure the time of the evolution of the system.

In conclusion, we observe $\phi(1020)$, $K^{\star0}(892)$, and $\overline{K^{\star0}}(892)$ from first-year data at RHIC taken with the STAR TPC. The measured $K^{\star0}/h^-$ is compared with $K^{\star0}/\pi$ from pp at ISR and e^+e^- at LEP. Although data indicate a slight enhancement in $K^{\star0}$ production per participant pair from pp to Au+Au, $K^{\star0}/K$ seems to decrease. A more detailed study including momentum distributions should be done with improved statistical and systematic precision from future Au+Au and pp runs at RHIC. We plan to measure the p_T spectra of $K^{\star0}$ and ϕ from this data set and future data sets. We will explore the feasibility of measuring many other resonances.

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